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Handbook for Developing Watershed Plans to Restore and Protect Our Waters

Chapter 8. Estimate Pollutant Loads

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8. Estimate Pollutant Loads

Handbook Road Map

Chapter Highlights

- Load estimation techniques
- Using models to estimate loads
- Available models
- Model selection
- Model application techniques
- Presenting pollutant loads

Read this chapter if...

- You're not sure how to estimate pollutant loads from your watershed sources
- You want information on simple or more detailed approaches for estimating loads
- You don't know how to select a watershed model that's right for your watershed and needs
- You want information on the various watershed models available and their capabilities
- You want to review the typical steps used in applying watershed models to estimate pollutant loads and evaluate source contributions
- You want some ideas on how to organize the results of your load estimation analysis and present pollutant loads

8.1 How Do I Estimate Pollutant Loads?

Early in the watershed characterization process, you identified and gathered available data and information to assess the watershed and created a data inventory. Then you conducted a preliminary data review, identified gaps, and collected additional data if needed. Finally, you analyzed the data to characterize the waterbody conditions and identify causes and sources, using the techniques discussed in chapter 7. Your next step is to estimate pollutant loads from watershed sources to target future management efforts. This step is essential to eventually satisfy element *b* (i.e., necessary load reductions) of the nine minimum elements. (☛Identifying load reductions is discussed in chapter 9.) This element is the component most often missing from current and past watershed plans, although it is one of the most important. Without knowing where the pollutants are coming from, you can't effectively control them and restore and protect your watershed. The loading analysis provides a more specific numeric estimate of loads from the various sources in the watershed. By estimating source loads, you can evaluate the relative magnitude of sources, the location of sources, and the timing of source loading. The loading analysis can help you plan restoration strategies, target load reduction efforts, and project future loads under new conditions. This chapter discusses the analysis and modeling techniques commonly used to estimate or to quantify pollutant loads.

An understanding of the watershed, built throughout the watershed planning process, is used as the basis for determining the appropriate method for quantifying the pollutant loads. You can use various approaches to do the loading analysis, and which one is right for you depends on several factors, including water quality parameters, time scale, source types, data needs, and user experience. Some loading analyses are focused on determining "how much" load is acceptable, whereas others focus on "source loads" that attribute loading to each category of sources in the watershed. For watershed planning purposes, source load estimates are desirable because the information can be used to support management planning and targeting of restoration resources. In general, the approach you choose should be the simplest approach that meets your needs.

Sometimes loading estimates have already been developed for watersheds. Check whether a previous study is available—a Total Maximum Daily Load (TMDL), Clean Lakes study, or other watershed-based program that might have required development of loading

Can TMDLs Be a Source of Loading Information?

As part of developing a Total Maximum Daily Load (TMDL), loading estimates are typically developed for point and nonpoint sources for the pollutants of concern. Remember that TMDLs are developed for specific pollutants, so they might not include all the pollutants that the watershed plan considers. TMDL documents, including the report, supporting modeling studies, and model input files, are typically available from the state or EPA. In these materials are estimates of existing loads, allowable loads (that meet water quality standards), and the load estimates for point sources (wasteload allocations) and nonpoint sources (load allocations). The load estimates are specified by categories of sources, such as generalized land use types (e.g., pasture). A TMDL can be an excellent source of loading estimates that is well documented and available. If you're using a TMDL, consider the age of the application and recognize that some changes might have occurred since the original analyses. Some areas might have new management activities that have reduced or changed loading. Other areas might have significant land use changes or development that could change estimates. In addition, TMDL analyses do not require implementation plans, so specific estimates of management techniques and their effectiveness are not necessarily included. Some additional or supplemental analysis is likely to be needed to estimate how the potential load reductions will be achieved.

estimates. Such studies can often be used to provide loading estimates appropriate for developing the watershed plan.

Stakeholders have an interest in the analysis and modeling techniques used to support decisionmaking. Engaging stakeholders in the evaluation and selection of analysis techniques can support more informed decisionmaking and buy-in for the approaches selected. However, the more complex techniques and modeling tools can be more difficult to describe, review, and interpret. One consideration in selecting models is the transparency of results to the affected community. Even the most complex models can be effectively described and provided for review through public meetings, workshops, and technical transfer opportunities. Simplified approaches, when sufficient for addressing the watershed concerns, can be more easily interpreted and adopted by the community.

Although approaches have different features, their application is typically best suited to many generalized watershed studies. Some of the more typical model selections are shown in table 8-1, although you should recognize that site-specific conditions might vary significantly. In each example the models are listed in order of complexity, simplest first. All of these approaches are discussed in this chapter.

Table 8-1. Example Approaches Used for Estimating Watershed Loads

Land Use	Sources/Concerns	Pollutants	Models
Agricultural	Grazing	Nutrients and sediment	GWLF AGNPS SWAT
Agricultural	Livestock and wildlife sources	Nutrients	Spreadsheet estimation STEPL SWAT HSPF
Agricultural	Cropland management, conservation tillage	Nutrients and pathogens	AGNPS SWAT
Mixed Use	Stormwater management Agriculture Residential	Sediment and nutrients	P8-UCM SWMM HSPF
Mixed Use	Stormwater management Agricultural	Pathogens	Spreadsheet estimation HSPF
Urban	Stormwater management Land use conversion, redevelopment	Sediment, nutrients, and metals	P8-UCM SWMM HSPF

Two general types of techniques for estimating pollutant loads are described in the following sections. First, techniques that directly estimate loads from monitoring data or literature values are discussed. These techniques are best suited to conditions where fairly detailed monitoring and flow gauging are available and the major interest is in total loads from a watershed. Second, watershed modeling techniques are described, including considerations in selecting models, available models, and the steps involved in applications. A wide range of models that can provide loads by sources, help predict future conditions, and evaluate multiple management practices are discussed.

8.2 Using Monitoring Data or Literature Values to Estimate Pollutant Loads

Commonly used approaches for estimating pollutant loads in watersheds involve using instream monitoring data or literature values (e.g., land use loading rates). These simple approaches can vary in detail or scope depending on the needs of the analysis and the available data. In most cases, they provide a coarse estimate of the pollutant loads entering a waterbody, without great detail on the contributing source or areas of concern. This section provides some examples of simple load estimation methods using available monitoring data and literature values.

8.2.1 Using Monitoring Data to Estimate Loads

Monitoring data can be used to directly estimate the pollutant loading entering a waterbody. Because the monitoring data represent instream conditions, the resulting estimate represents the total loading from a watershed upstream of the monitoring point. This type of estimate does not attribute loads to particular sources or areas. This generalized loading can help to evaluate downstream impacts, can be used to calculate a per acre loading, and can be used for comparison of local loadings with those of other areas. This loading estimate is also based on historical conditions because it is directly estimated from monitoring data. It cannot be used to directly predict how loadings might change in the future.

Monitoring data typically include periodic samples of water quality concentrations of pollutants and flow gauging. Flow multiplied by concentration can be used to calculate the load for a specific period. However, water quality sampling is not continuous; it is normally done periodically (e.g., weekly, monthly). Load duration curves are a common approach to using sporadic flow and water quality data to estimate the average total loading at watershed monitoring stations (☛see section 7.2.5). In addition, various statistical techniques have been developed to estimate loading from periodic sampling and flow gauging data. These techniques build relationships between flow and concentration to help predict or estimate loading during time periods when there is no sampling. Flow gauging information is more likely to be available on a daily basis than the more expensive water quality sampling and laboratory analysis.

The major limitation of these approaches is the aggregate nature of the loading estimate. You can use statistical load estimation techniques to directly estimate loadings from a drainage area or watershed for which monitoring data are available, but this method is not applicable for estimating individual source loading or predicting future changes in loading. If you have a robust dataset throughout the watershed and can apply the load estimation at key areas (e.g., upstream and downstream of suspected sources), you can potentially evaluate the relative magnitude and impact of different sources. Often, however, data are not available for a full range of flow conditions at more than a couple locations in a watershed. If this type of methodology is used in developing your watershed plan, be sure to include future source characterization or monitoring as part of the implementation plan to further refine source loads and target control efforts.

These techniques are also completely reliant on a long period of record of monitoring information to develop the loading estimates. Uncertainty can be calculated from the statistical process, providing the advantage of a system for measuring accuracy. However, continuous flow gauging is available only in limited locations, and typically for large watersheds. You should carefully check the availability and relevance of the data when considering using direct calculations of load. Make sure to check that flow and water quality sampling were conducted at the same time. Ideally, a continuous flow gauging record is available so you can evaluate the changes in flow and seasonal patterns.

The following methods for directly calculating watershed loads are discussed in the sections below:

- FLUX
- Regression of pollutant load and flow using Minimum Variance Unbiased Estimator (MVUE)

FLUX

FLUX, developed by Walker (1996) for the U.S. Army Corps of Engineers, is an interactive computer program used to estimate the loads of nutrients or other water-quality constituents such as suspended sediment. This technique was developed as a companion to the Bathtub model, a commonly used lake modeling technique (Walker 1985, 1986, 1990). The following six estimation algorithms are available in FLUX: (1) direct-mean loading, (2) flow-weighted concentrations (ratio estimate), (3) modified ratio estimate, (4) first-order regression, (5) second-order regression, and (6) regression applied to individual daily streamflow. FLUX maps the flow versus concentration relationship developed from the sample record onto the entire flow record to calculate total mass, streamflow, and associated error statistics. FLUX also provides an option to stratify the data into groups on the basis of flow to improve the fit of the individual models.

Data requirements for FLUX include

- Constituent concentrations, collected on a weekly to monthly frequency for at least a year
- Date collected

- Corresponding flow measurements (instantaneous or daily mean values)
- Complete flow record (daily mean streamflow) for the period of interest.

Regression of Pollutant Load and Flow

A very simple approach to estimating pollutant logs is to use available water quality and flow data to develop a regression equation representing the relationship between the pollutant load and flow magnitude. That equation is then used to estimate pollutant loads on days when flow is available but water quality data are not. For example, the approach can be applied to a flow gauging station that has sporadic water quality data but continuous flow data to estimate water quality and, therefore, pollutant loading on unmonitored days.

However, many pollutant loads, such as sediment, are storm-driven and observed values often span several orders of magnitude. For this reason, the instream sediment load versus flow relationship tends to be linear when examined on a logarithmic scale. This can introduce a large amount of error when using a regression approach to estimate pollutant loads. To reduce this error and remove the bias from the regression analysis, a log transform regression approach can be used. The U.S. Geological Survey (USGS) recommends Minimum Variance Unbiased Estimator or MVUE (Cohn and Gilroy 1991) as one of the methods for bias correction. The objective of this method is to yield an unbiased estimate with the smallest possible variance. ☛Go to http://co.water.usgs.gov/sediment/bias.frame.html for more information on MVUE.

8.2.2 Using Literature Values to Estimate Loads

One of the simplest techniques for estimating pollutant loads involves calculating loads on the basis of land use areas and representative loading rates (i.e., load per area of land). An example of this approach is shown in figure 8-1. In this case the load is a function of a single factor, "land use area," based on a predefined loading rate. This simple presentation has the benefit of being very easy to apply and explain, but simplicity also results in several limitations. The loading rate is a static value and does not account for temporal or spatial variations in environmental conditions such as precipitation and soils.

Because the loading estimate is dependent on the loading rate used in the calculation, it's important to identify values that are realistic for your watershed. Loading rates for land uses can vary widely throughout the nation depending on precipitation, source activity, and soils, and in some areas estimates are not available. Regional loading rates might be available from scientific literature or watershed studies conducted in nearby watersheds. Otherwise, use national estimates with caution, recognizing that the values might not be representative of your watershed.

The export coefficient model is the simplest type of pollutant runoff model because all factors that effect pollutant movement are combined into one term—the export coefficient. For example, the total pollutant load (in kilograms per year) is calculated by multiplying the land use areas (in hectares) by the export coefficients (in kilograms per hectare per year) for various activities, such as corn, pasture, and residential use and summing the products. Export coefficients for the various land uses can be obtained from literature searches. The table below presents an example of an export coefficient spreadsheet used to obtain a rough estimate of the effects of various land use activities on watershed nutrient loading.

Example of Pollutant Budget Estimation Using Export Coefficient Model

Land Use	Area (ha)	Nitrogen Export Coefficient (kg/ha/yr)	Total Nitrogen Load (kg/yr)	Percent of Nitrogen Load	Phosphorous Export Coefficient (kg/ha/yr)	Total Phosphorous Load (kg/yr)	Percent of Phosphorous Load
Forest	100	1.8	180	0.91	0.11	11	0.52
Corn	200	11.1	2220	11.24	2	400	18.95
Cotton	100	10	1000	5.6	4.3	430	20.37
Soybeans	20	12.5	250	1.27	4.6	92	4.36
Small Grain	50	5.3	265	1.34	1.5	75	3.55
Pasture	300	3.1	930	4.71	0.1	30	1.42
Feedlot or Dairy	5	2,900	14,500	73.39	220	1,100	52.11
Idle	30	3.4	102	0.52	0.1	3	0.14
Residential	20	7.5	150	0.76	1.2	24	1.14
Business	10	13.8	138	0.7	3	30	1.42
Industrial	5	4.4	22	0.11	3.8	19	0.9
Total	840	-	19,757	1	-	2,111	100

Note: Agricultural coefficients are from Reckhow et al. (1980), and urban coefficients are from Athayde et al. (1983).

Figure 8-1. Example of an application of export coefficients to calculate pollutant loads.

North Carolina State University's WATER, Soil, and Hydro-Environmental Decision Support System (WATERSHEDSS) provides a tool for land managers to evaluate pollutant budgets and agriculture management practices. ☛To download the tool for calculating loads using export coefficients go to www.water.ncsu.edu/watershedss. The system also includes a database of agricultural management practices, references on nonpoint source pollutants and sources, and an annotated bibliography of nonpoint source literature.

Empirical relationships documented in scientific literature are another option for estimating pollutant loads. Empirical relationships are those based on observed data and are represented by an empirical equation. An example of an empirical relationship relating watershed characteristics to pollutant loading is the Simple Method (Schueler 1987). The Simple Method is a lumped-parameter empirical model used to estimate stormwater pollutant loadings under conditions of limited data availability. Because this is a lumped approach, it assumes the physical characteristics for land units within a subwatershed are homogeneous, thereby simplifying the physical representation of the subwatershed. The approach calculates pollutant loading using drainage area, pollutant concentrations, a runoff coefficient, and precipitation data. In the Simple Method, the amount of rainfall runoff is assumed to be a function of the imperviousness of the contributing drainage area. More densely developed areas have more impervious surfaces, such as rooftops and pavement, causing more stormwater to run off rather than being absorbed into the soil. The Simple Method includes default and suggested values for the equation parameters, or values can be watershed-specific based on monitoring data or local information.

Where to Get Export Coefficients

Lin (2004) summarizes and reviews published export coefficient and event mean concentration (EMC) data for use in estimating pollutant loading into watersheds. Some references included in that review and commonly used for export coefficients include

Beaulac, M.N., and K.H. Reckhow. 1982. An examination of land use-nutrient export relationships. *Water Resources Bulletin* 18(6): 1013-1024.

Reckhow, K.H., M.N. Beaulac., and J.T. Simpson. 1980. *Modeling phosphorus loading and lake response under uncertainty: A manual and compilation of export coefficients*. EPA-440/5-80-011. U.S. Environmental Protection Agency, Office of Water Regulations, Criteria and Standards Division, Washington, DC.

8.3 Watershed Modeling

Models provide another approach for estimating loads, providing source load estimates, and evaluating various management alternatives. A model is a set of equations that can be used to describe the natural or man-made processes in a watershed system, such as runoff or stream transport. By building these cause-and-effect relationships, models can be used to forecast or estimate future conditions that might occur under various conditions. Models can be highly sophisticated, including many specific processes such as detailed descriptions of infiltration and evapotranspiration. Models can also be very generalized, such as a simple empirical relationship that estimates the amount of runoff based on precipitation. Some models are available as software packages, whereas simple models or equations can be applied with a calculator or spreadsheet. Compared to the simple approaches discussed in section 8.2, models add more detailed procedures that represent the separate processes of rainfall, erosion, loading, transport, and management practices. By separately addressing each process, models can be adapted to local conditions, and the simulation can be made more sensitive to land use activities and management changes.

This section discusses the role of modeling in watershed planning, the types of models available, how to select appropriate models for your watershed study, and setting up and applying models for a watershed.

Definitions

Model: A representation of an environmental system through the use of mathematical equations or relationships.

Modeling system: A computer program or software package that incorporates a model and input and output systems to facilitate application.

Model application: The use of a model or models to address defined questions at a specific location.

The Watershed Continuum

One way to represent the watershed is by following the flow of water from land areas to streams and rivers, through lakes, to estuaries, and ultimately to the ocean. When we evaluate water quality standards, the focus is typically on the waterbody of concern. For total maximum daily loads (TMDLs) the dominant use of models is to evaluate the relationship between human actions (e.g., land use management or wastewater treatment) and the impaired downstream waterbody (e.g., river, lake, or estuary). Human actions, such as management practices, land use activities, direct withdrawals of drinking or cooling water, and discharges of wastewater, can all be considered factors that affect watersheds at the land, river, lake, or estuary level.

For TMDLs, modeling typically focuses on describing the linkage between human activities and impaired waters. This "linkage analysis" is necessary to demonstrate that the plan will achieve water quality standards (USEPA 1999a, 1999b, 2001a). For watershed management plans, analysis should focus in more detail on the management actions and land-based activities that will be used to meet water quality goals. In this case the analysis is focused on determining how best to address the management needs. Although modeling for watershed management planning is similar, the focus on management typically will result in more detailed, localized modeling. This localized modeling and evaluation can be performed separately or in tandem with TMDL or other modeling efforts. The models described in this chapter will emphasize the management and localized evaluations typically employed in watershed planning and provide references and links for other types of supporting models.

8.3.1 Factors to Consider When Selecting a Model

Before selecting the most appropriate model, you should define the approach for the specific study. An approach may include one or more models, multiple analysis procedures, and a variety of input data to address the project needs. Selecting the appropriate model application or approach requires an understanding of the range of complexity of the analytic techniques and a clear understanding of the questions to be answered by the analysis. Note that the model application might include the following:

- Various levels of detail for each component
- More than one model to address different waterbodies, pollutants, or stressors
- An available modeling system; a modification of an existing model; or a local, custom model
- A model documentation plan

Determining the model application also means defining the data needs and the accuracy of the modeling results. To select a model and associated application needs, first examine the questions that need to be answered. The following are questions that models are typically used to answer:

- Will the management actions result in meeting water quality standards?
- Which sources are the main contributors to the pollutant load targeted for reduction?
- What are the loads associated with the individual sources?
- Which combination of management actions will most effectively meet the identified loading targets?
- When does the impairment occur?

- Will the loading or impairment get worse under future land use conditions?
- How can future growth be managed to minimize adverse impacts?

Evaluating questions by using models requires looking at and comparing results in terms of load, concentration, flow, or another measurement. This comparison should consider the indicators identified to evaluate the watershed concerns (☛section 4.6). For example,

- A lake eutrophication problem might focus on predicting the total nitrogen and phosphorus load.
- A river with an attached algae problem might need models that can predict concentrations of dissolved nitrogen and phosphorus during low-flow conditions.
- An area with beach closures due to pathogens might focus on predicting pathogen counts and the frequency of water quality standards violations.
- A concern over sediment in streams might focus on changes in hydrology, stream morphology, or sediment loading from erosion-prone areas.

In each case the predictions of the model should be evaluated on the basis of the indicators identified for meeting and tracking the goals of the watershed management plan. The indicators used will often dictate the level of detail of the study. Predicting short-term concentrations, such as a concentration of aluminum, may require more detailed analysis of flow and pollutant transport. The model should support the development of source loads and estimates of their magnitude, and it should support the development of the appropriate pollutant load reduction estimates.

In defining a model application for your watershed, keep in mind four general considerations:

1. Is the approach appropriate to your specific situation, answering the questions needed to develop a watershed plan (relevance)?
2. Has the modeling system been shown to give valid results (credibility)?
3. Is the model easy enough to learn and use that you are likely to succeed at obtaining useful results (usability)? Are data available to support the model (usability)?

Additional Modeling Definitions

Field scale. Some applications are focused on small areas at the subbasin or smaller level. Field-scale modeling usually refers to geographic areas composed of one land use (e.g., a cornfield).
Physically based models. A physically based model includes a more detailed representation of fundamental processes such as infiltration. Applying physically based models requires extensive data and experience to set up and test the model. HSPF and SWAT both include physically based processes, although many simplifications are still used.
Lumped model. A model in which the physical characteristics for land units within a subwatershed unit are assumed to be homogeneous is referred to as a "lumped" model. Discrete land use areas within a subwatershed area are lumped into one group.
Mechanistic model. A mechanistic model attempts to quantitatively describe a phenomenon by its underlying casual mechanisms.
Numerical model. A numerical model approximates a solution of governing partial differential equations that describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.
Steady state model. A steady state model is a mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Steady state models are typically used to evaluate low-flow conditions.
Dynamic model. A dynamic model is a mathematical formulation describing the physical behavior of a system or a process and its temporal variability.

4. Is the model able to predict water quality changes based on the changes planned for your watershed management plan (utility)?

Each of these considerations is discussed below.

Relevance

Relevance Considerations

- ☑ The model can represent the land uses and processes that are most important in your watershed
- ☑ The model predicts the pollutants you're concerned about

Even if the model has been reviewed in the literature and has been applied in other watersheds, you need to make sure that it's relevant to the needs of your watershed. For example, a model developed and tested only in urban areas, or even in rural areas that are mostly forested, is not a good choice for a watershed that consists almost entirely of agricultural row crops or mixed uses. If flow-through tile drains are one of the main pathways through which water reaches the stream in your watershed, a model that does not include artificial drainage is probably not a good choice. For specialized cases, such as tile drainage, a custom modeling application might be needed. Many models have been developed for specific pollutants. Some specialize in sediment only because reducing erosion was historically the mission of modeling conducted by the U.S. Department of Agriculture (USDA). Many models give results for sediment, nutrients, and perhaps pesticides, but not for microbial contaminants.

Credibility

Credibility Considerations

- ☑ Model validations have been published in a peer-reviewed journal
- ☑ The model is in the public domain, and the source code is available on request

Because it's not possible to know in advance how accurate the results of a specific model will be, you need to rely on what others have found. Scientists rely on peer review of journal articles written about the use of a model. A quick rule of thumb is to use only models whose validation has appeared in respected peer-reviewed journals. That way you benefit from the time other modelers and scientists have spent reviewing the model. All the models reviewed in this handbook have been validated, at least to some extent.

Most models distributed in the public domain have been developed by government agencies (e.g., EPA or USDA) or universities and are freely available. However, some consultants use proprietary models, which are privately owned software. Such models cannot be checked because the code is not available to others. It is generally a good idea to use nonproprietary models if possible. Proprietary models normally require a purchase fee and have limited distribution rights. Limiting distribution and review might affect acceptance by the stakeholders.

Usability

Accuracy of prediction is important, but if the model will not answer the questions you need to develop your watershed plan, it will not be useful.

Documentation that explains the parameters, how to get them, and reasonable values is essential to ensure that the model is usable. New users might need some sort of training to learn how to use the model. Finally, model users sometimes run into questions that are not addressed in the documentation. A model that will be widely used needs to have user support available. The support can be in the form of a person who provides technical assistance or a list server where other users can answer questions.

Usability Considerations

- ☑ Documentation, training, and support are available
- ☑ The model can be run with data that are generally available or data that can be obtained with reasonable effort
- ☑ The model and user interface are reliable and thoroughly tested

Obtaining input data is often the most time-consuming and difficult part of running a model. This often comes as a surprise to those who have not used models. Models generally require data on land cover, land management (such as agricultural practices), factors that affect the rate at which water can flow into the soil and recharge ground water (usually geology or soil type), and other information about the land in the watershed. In addition, daily or even hourly weather data, including precipitation and temperature, are usually required. Other weather data that are more difficult to obtain, such as relative humidity and wind speed, might be required. For models to be calibrated, accurate input data are needed. Modeling systems, such as EPA BASINS, have compiled much of the basic data needed to run the model; however, this coarse, national-scale data will not always be accurate enough to give useful results, particularly in small watersheds. Other national, publicly available databases are available from USGS and other sources. Nevertheless, parameters like soil nutrient concentrations or fertilizer applications, particularly those associated with agricultural production and other management activities, are not available nationally and must be obtained locally.

Utility for Watershed Planning

Using a model to predict the impact of changes in a watershed requires that the model be able to represent those changes. Models represent changes in watershed management in very different ways. You'll need to consider what management practices are likely to be applied in your watershed and whether the model can be used to evaluate their benefits. In many cases other analyses are used to supplement a model; sometimes additional spreadsheet calculations can be used to check on the potential load reductions from various methods. In addition, you might want to consider how the model will be used in the future. Will it be used to check future changes in management or as a tool to track progress? If the model will be used as an ongoing planning tool, remember to consider the complexity of the model and the availability of trained staff to apply the model.

Utility Considerations

- ☑ The model or supplemental tools are able to predict the likely water quality impacts of the land use or management changes you are considering in your watershed plan

8.3.2 Using Watershed Modeling Tools to Evaluate Loads

Watershed models use a set of equations or techniques to analyze the following key components of the watershed system.

- **Rainfall/runoff:** The description of precipitation, infiltration, evaporation, and runoff. This portion of a model is used to calculate the amount and timing of runoff from a land area. Runoff is also related to erosion and to sediment and pollutant transport. In cold-climate watersheds, it might be important to use a model that can represent snowmelt/runoff conditions.

- **Erosion and sediment transport:** The description of soil detachment, erosion, and sediment movement from a land area. In more detailed approaches this is linked to the runoff calculation and might include sediment deposition.

- **Pollutant loading:** The wash-off of pollutants from a land area. In generalized approaches this is a loading factor. More detailed techniques link pollutant wash-off to hydrology and sediment movement.

- **Stream transport:** The stream portion of watershed models, which is needed, at a minimum, to collect the runoff/sediment/pollutants from the various land areas. More detailed models include evaluation of instream behavior of sediment and pollutants. Processes may include deposition, resuspension, decay, and transformation.

- **Management practices:** A management practice can be land-based (e.g., tillage or fertilizer application), constructed (e.g., stormwater ponds), or input/output to a stream (e.g., wastewater treatment). Land-based management can be generalized (e.g., number of acres treated) or specific (e.g., field-specific practices). Some models include more detailed simulation techniques. For example, a pond analysis might include sediment settling and first-order decay of pollutants.

First, the land areas are described, typically in terms of land use, soils, and slope, which are the key features that affect runoff, erosion, and pollutant loadings. Second, the management practices present in the watershed are considered. Third, the stream and river transport is considered. Each component of this analysis can be considered at various levels of detail. For example, in describing runoff there are several distinct levels of analytical detail (table 8-2). Each level considers more specific factors and processes. The more detailed the equations used to build the modeling system, the more parameters need to be estimated and the more detailed the evaluation of the model performance needs to be. For each situation the analyst will need to select the type of model, along with the associated level of detail, that is consistent with the objectives of the analysis.

Table 8-2. Various Levels of Detail for Simulating Runoff

Level of Detail	Equation	Assumptions
Generalized	Percentage of rainfall that runs off the land into the water (rational method/regression of rainfall and runoff observations)	Simple relationship between rainfall and runoff. One factor represents the loss associated with evaporation and plant uptake. No special consideration of slope or soil characteristics. No consideration of soil moisture.
Mid-level	CN	Simple relationship based on studies across the country. Varies depending on soil type, vegetation, and slope. Considers soil moisture (antecedent moisture condition). Does not consider variations in storm intensity; uses daily rainfall.
Detailed	Infiltration equation	Describes infiltration of water and evapotranspiration. Considers soil moisture and soil type, vegetation, and slope. Considers variations in storm intensity. Time step is typically hourly rainfall or less.

Note: CN = curve number.

Model applications to specific watersheds often include a mixture of levels of detail depending on the problems being considered. For example, a modeling analysis supporting an agricultural nutrient management initiative might include very detailed descriptions of land behavior, such as nitrogen use by plants, and a very simplified analysis of stream transport. A study considering the upgrade of a wastewater treatment plant would include a detailed examination of the stream conditions in summer and a very simplified representation of land use activities. Table 8-3 describes some of the variations in the level of detail that might be considered in a watershed planning project.

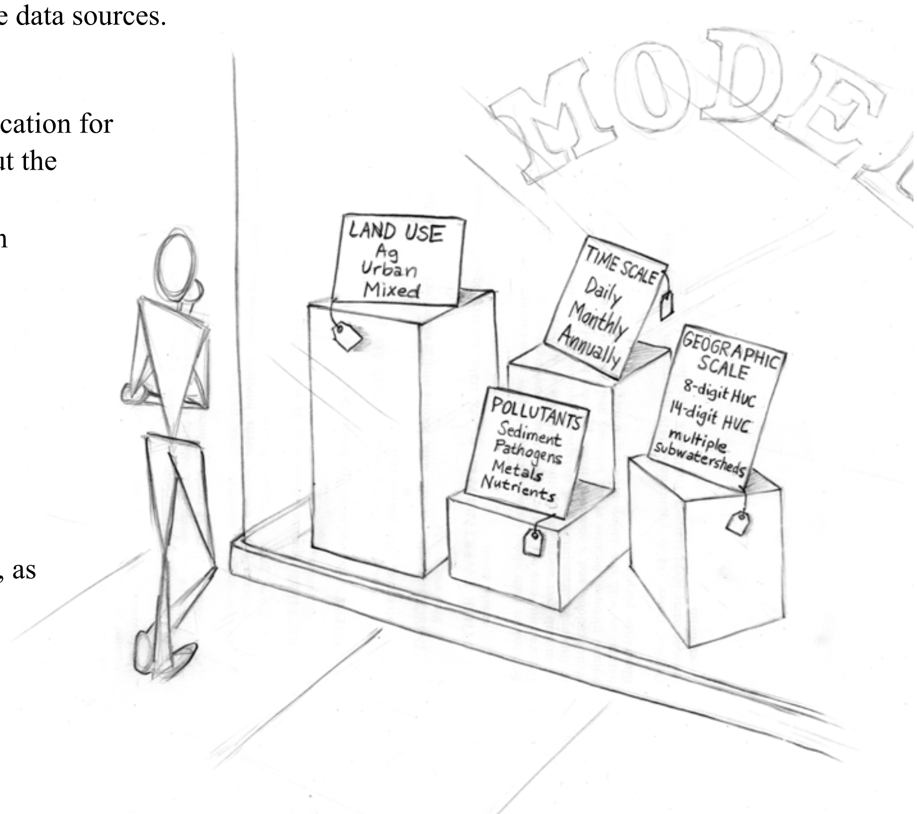
Table 8-3. Levels of Detail in Watershed Models

Element	Generalized	Mid-level	Detailed
Land			
Land use	Category (Agriculture)	Subcategory (Cropland)	Specific (Corn, ridge-tilled)
Slope	N/A	Average for area	Average for specific location
Soil moisture	N/A	Antecedent moisture condition (3 levels)	Calculated
Hydrology	Percent runoff	CN	Infiltration equations
Pollutants	Single	Multiple	Chemical and biological interactions between pollutants
Load	lb/ac/year	lb/day; daily average concentration	lb/hr; hourly average concentration
Management Practices			
Management Practices	Percent removal	Percent removal and estimated volume captured	Hydrology Deposition/settling First order decay and transformation
Streams/Rivers			
Hydrology	Single flow, steady state	Single flow, steady state	Continuous or variable flow
Water quality	Regression, simple relationships	Eutrophication cycle	Eutrophication cycle, carbon/nutrient/BOD processes
Toxic substances	Regression, simple relationships	Settling, 1st order decay	Transformation, biodegradation, other processes

Note: CN = curve number; BOD = biochemical oxygen demand.

8.3.3 Model Selection and Application Process

With so many models available, how do you know which one to choose? The development of a modeling analysis involves more than selecting a modeling tool. The application of a model for decisionmaking also involves designing and implementing an analysis that addresses the management questions. Typically this involves a combination of data analysis techniques, as described in chapter 7, and compilation and organization of disparate data sources.



Described below are the key steps for selecting and designing a modeling application for watershed planning purposes. Throughout the watershed process you've built an understanding of the watershed—through scoping, stakeholder input, and data collection and analysis. The design of the modeling approach should build on this understanding and help you to better understand the watershed.

1. Consider the objectives of the analysis. During the scoping process the key objectives of the study are identified, as well as the general modeling needs and watershed characteristics. The specific objectives and associated indicators will help to define the pollutants that the model might need to consider.

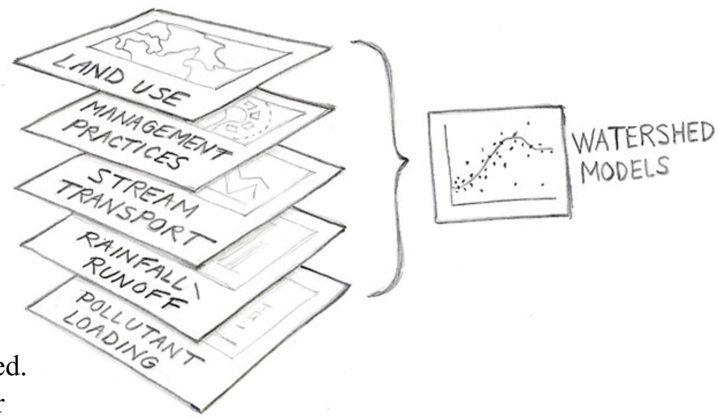
2. Define the specific questions that the modeling will be used to answer. As discussed earlier in the chapter, before selecting a model, the analyst should first carefully define the questions that the model will be used to answer. The questions should directly relate to the overarching objectives of the study. The following are examples of modeling questions:

- What are the sources of the pollutant load?
- Where can management practices be targeted to best meet load reduction requirements?
- What combination of management practices will result in reducing the load to the desired level and meeting water quality goals?

3. Select the modeling approach that will address the questions. The modeling approach includes the model(s) to be used, the input data processing requirements and data sources, the model testing locations and data sources, and the output analysis. The modeling approach defines how the model will be applied, not just what the model is. The approach provides the entire plan or road map for analysis and is broader than the selection of a model.

4. Set up the model. As required by the modeling approach identified above, the input data are collected and processed for the model (or models). Typical data inputs include the following:

- Land use
- Soils
- Slope
- Activities, management locations, and types
- Monitoring data—flow and water quality
- Meteorologic data—precipitation and temperature



Each dataset might require some preprocessing before input. For example, land use information might be selectively updated where new development has occurred. Sometimes multiple land use datasets are combined. For example, one data source might provide a more detailed breakdown of forest types and could be used to add detail to a broader land use coverage. Some models require developing categories of land use, soil, and slope characteristics. Resulting units could include corn fields with B soils (a hydrologic soil group defined by the USDA) and moderate slopes, pasture with C soils and steep slopes, and so on. User's guides and the selected modeling references provide some additional guidance on data preprocessing needs for individual models. Much of the data required for watershed models is discussed in chapter 5.

5. Test the model's performance. Regardless of the complexity or detail of the modeling approach, appropriate testing (calibration and validation) of model accuracy should be performed. Remember that modeling results need a reality check before they are used to support a loading analysis or evaluation of management scenarios. If data are available, the model should be calibrated and validated to ensure accurate representation of the watershed processes. When data are limited, you should also compare model results to literature values and data from surrounding watersheds to review the integrity of the results. Do the loads seem realistic given observed concentrations and flows or documented loads in nearby watersheds? Do the simulation results make sense given the watershed processes? For example, if a watershed model produces monthly loads, do the higher loads occur during the times of higher observed flows and concentrations? Or, if a model provides output from both ground water and surface water, do the relative contributions make sense given the topography and geology of

What's the Difference between Model Validation and Calibration?

Calibration and validation are two separate procedures in model development and testing. Available monitoring data are separated into two separate time periods for testing. Using one dataset, calibration parameters are adjusted, within reasonable ranges, until a best fit to observed data is generated. Using the second dataset, validation is performed by keeping the parameter set constant and testing the performance of the model. Time periods for calibration and validation are carefully selected to include a range of hydrologic conditions.

the area? Watershed models are meant to represent the processes affecting runoff and pollutant transport and loading. Use your knowledge of the area to reality-check the model representations and output. ☛More information on model calibration and validation is provided in section 8.4.5.

6. Apply the model and interpret the results. The model is applied to evaluate the range of conditions required for addressing the modeling questions. For example, a model might be used to evaluate the nutrient loading over a 10-year period. Output postprocessing might include developing annual and monthly loading summaries by source category and evaluating of seasonal and annual variation. Multiple model applications might be used to consider changes in land use, installation of management practices, and alterations in cultivation techniques. Output can be processed to support development of essential elements of the watershed plan (source controls, magnitude of sources, and pollutant load reduction estimates).

7. Update the model to include new information or refine assumptions. Often after the initial management planning study is complete, additional data are collected or new information is discovered. The model can be updated periodically to further refine and test performance and update management recommendations, if appropriate.

Selection and execution of an appropriate modeling approach can support the development of a watershed management plan. Use caution in selecting an approach consistent with the available data, the specific questions to be addressed, and the type of management. Data analysis is an ongoing process in which modeling is only one potential tool. In many cases, simplifed techniques or statistical analysis is adequate to evaluate watershed conditions and no formal modeling is required. Throughout the process, focus on using the most simple methods appropriate to answering the questions at hand.

8.3.4 What Models Are Available?

Various modeling systems have been developed and used to answer a wide range of environmental questions. This handbook focuses on selected models that are publicly available and have a track record of application and use. The models are commonly used in TMDLs and other watershed studies. They represent a range of complexity and are applicable to a variety of pollutants and pollutant sources.

Although these models are supported by EPA and included in this handbook, other similar watershed models might be appropriate for use in developing your watershed plan. An inventory of available models that evaluates the models across a set of key charactistics is provided in table 8-4. These characteristics were selected to help differentiate among available tools and to describe areas of emphasis, complexity,

Table 8-4. Overview of Several Available Watershed Models

		Type		Level of Complexity			Timestep				Hydro-logy		Water Quality							Types of BMPs				
Model Acronym	Source	Grid-based	Stream routing included	Export coefficients	Loading functions	Physically based	Sub-daily	Daily	Monthly	Annual	Surface	Surface and groundwater	User-defined	Sediment	Nutrients	Toxics/pesticides	Metals	BOD	Bacteria	Detention basin	Infiltration practices	Vegetative practices	Wetlands	Other structures
AGNPS (event based)	USDA-ARS	●	●	–	–	●	●	–	–	–	●	–	–	●	●	●	–	–	–	●	–	●	–	–
AnnAGNPS	USDA-ARS	–	●	–	–	●	–	●	–	–	●	–	–	●	●	●	–	–	–	●	–	●	–	–
BASINS	EPA	–	●	●	●	●	●	●	–	–	●	●	●	●	●	●	●	●	●	●	–	●	–	●
DIAS/ IDLMAS	Argonne National Laboratory	–	–	–	–	–	–	–	–	●	–	–	–	●	–	–	–	–	–	–	–	–	–	–
DRAINMOD	North Carolina State University	–	–	–	–	●	●	–	–	–	–	●	–	–	●	–	–	–	–	–	–	–	●	–
DWSM (event based)	Illinois State Water Survey	–	●	–	–	●	●	–	–	–	●	–	–	●	●	●	–	–	–	●	●	–	–	–
EPIC	Texas A&M University–Texas Agricultural Experiment Station	–	–	–	–	–	–	●	–	–	●	–	–	●	●	●	–	–	–	●	●	–	●	–
GISPLM	College of Charleston, Stone Environmental, and Dr. William Walker	–	●	–	●	–	–	●	–	–	●	–	–	–	●	–	–	–	–	–	–	–	–	–
GLEAMS	USDA-ARS	–	–	–	–	–	–	●	–	–	●	–	–	●	●	●	–	–	–	–	–	–	–	–
GSSHA	USACE	●	●	–	–	●	●	–	–	–	–	●	–	●	–	–	–	–	–	●	●		●	●
GWLF	Cornell University	–	●	–	●	–	–	–	●	–	–	●	–	●	●	–	–	–	–	–	–	●	–	–
HEC-HMS	USACE	–	●	–	–	●	●	–	–	–	●	–	–	–	–	–	–	–	–	–	–	–	–	–
HSPF	EPA	–	●	–	–	●	●	–	–	–	–	●	●	●	●	●	●	●	●	–	–	–	–	–
KINEROS2 (event based)	USDA-ARS	–	●	–	–	●	●	–	–	–	●	–	–	●	–	–	–	–	–	●	–	●	–	●
LSPC	EPA and Tetra Tech, Inc.	–	●	–	–	●	●	–	–	–	–	●	●	●	●	●	●	●	●	●	–	●	–	●
Mercury Loading Model	EPA	–	–	–	–	●	–	–	–	●	●	–	–	–	–	–	●	–	–	–	–	–	–	–
MIKE SHE	Danish Hydraulic Institute	–	●	–	–	●	●	–	–	–	–	●	–	–	–	–	–	–	–	–	–	–	–	–
MINTEQA2	EPA	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	●	–	–	–	–	–	–	–
MUSIC	Monash University, Cooperative Research Center for Catchment Hydrology	–	–	–	–	●	●	–	–	–	●	–	●	–	–	–	–	–	–	●	●	●	●	●

Table 8-4. (continued)

		Type		Level of Complexity			Timestep				Hydrology		Water Quality							Types of BMPs				
Model Acronym	Source	Grid-based	Stream routing included	Export coefficients	Loading functions	Physically based	Sub-daily	Daily	Monthly	Annual	Surface	Surface and groundwater	User-defined	Sediment	Nutrients	Toxics/pesticides	Metals	BOD	Bacteria	Detention basin	Infiltration practices	Vegetative practices	Wetlands	Other Structures
P8-UCM	Dr. William Walker	–	–	●	●	–	●	–	–	–	●	–	●	●	●	–	●	–	–	●	●	●	–	●
PCSWMM	Computational Hydraulics Int.	–	●	–	●	●	●	–	–	–	–	●	●	●	●	●	●	–	●	●	●	–	–	●
PGC – BMP	Prince George's County, MD	–	–	–	●	–	●	–	–	–	–	–	–	●	●	–	●	–	–	●	●	●	●	●
REMM	USDA-ARS	–	–	–	–	–	–	–	–	–	–	–	–	●	●	●	●	–	–	–	–	●	–	–
SHETRAN	University of Newcastle (UK)	–	●	–	–	●	●	●	–	–	–	●	–	●	–	–	–	–	–	–	–	–	–	–
SLAMM	University of Alabama	–	–	–	–	–	●	–	–	–	●	–	–	●	●	–	●	–	–	●	●	●	●	●
SPARROW	USGS	–	●	–	–	–	–	–	–	●	●	–	–	●	●	●	–	–	–	–	–	–	–	–
STORM	USACE (Mainframe version), Dodson & Associates, Inc. (PC version)	–	–	●	–	●	●	–	–	–	●	–	–	●	●	–	–	–	●	–	–	–	–	●
SWAT	USDA-ARS	–	●	–	–	●	–	●	–	–	–	●	–	●	●	●	●	–	–	●	●	●	–	●
SWMM	EPA	–	●	–	–	●	●	–	–	–	–	●	●	●	●	●	●	●	●	●	●	–	–	–
Toolbox	EPA	–	●	–	–	●	●	–	–	–	–	●	●	●	●	●	●	●	●	●	–	●	–	●
TOPMODEL	Lancaster University (UK), Institute of Environmental and Natural Sciences	–	–	–	–	●	●	●	–	–	–	●	–	–	–	–	–	–	–	–	–	–	–	–
WAMView	Soil and Water Engineering Technology, Inc. (SWET) and EPA	●	●	–	–	●	●	–	–	–	–	●	–	●	●	●	●	–	●	●	●	●	●	●
WARMF	Systech Engineering, Inc.	–	●	–	–	●	–	●	–	–	–	●	–	●	●	●	●	●	●	–	–	–	●	●
WEPP	USDA-ARS	–	–	–	–	●	–	●	●	●	–	●	–	●	–	–	–	–	–	–	●	–	–	–
WinHSPF	EPA	–	●	–	–	●	●	–	–	–	–	●	●	●	●	●	●	●	●	–	–	–	–	–
WMS	Environmental Modeling Systems, Inc.	–	●	–	–	●	●	–	–	–	–	●	●	●	●	●	●	●	●	●	●	–	●	●
XP-SWMM	XP Software, Inc.	–	●	–	–	●	●	–	–	–	–	●	●	●	●	●	●	●	●	●	●	–	–	●

– Not supported
● Supported

and types of pollutants considered. Key characterization factors include the following:

- **Type.** “Landscape only” indicates that the model simulates only land-based processes; “comprehensive” models include land and stream and conveyance routing.

- **Level of complexity.** Complexity in watershed models is classified as three levels. Export functions are simplified rates that estimate loading based on a very limited set of factors (e.g., land use). Loading functions are empirically based estimates of load based on generalized meteorologic factors (e.g., precipitation, temperature). Physcially based models include physically based representations of runoff, pollutant accumulation and wash-off, and sediment detachment and transport. Most detailed models use a mixture of empirical and physically based algorithms.

- **Time step.** Time step is the unit of time (e.g., hourly, monthly) for which a model simulates processes and provides results. The table identifies the smallest timestep supported by a model. If larger output timesteps are needed, model output can be summarized from smaller timesteps.

- **Hydrology.** This criterion identies whether a model includes surface runoff only or surface and ground water inputs are considered.

- **Water quality.** Water quality capabilities are evaluated based on the pollutants or parameters simulated by the model.

- **Types of management practices.** The types of management practices simulated by the models are indicated in the table.

Even if you’re not planning to run the model yourself, it’s helpful to know the capabilities and requirements of the major types of watershed models so you can “talk the talk” and make informed decisions about how to proceed with your data analysis. Remember that typically it is not the model itself that causes problems but the matching of the model to local conditions, key assumptions, and interpretation of model outputs.

☛Additional detailed information on available models is provided in EPA’s *Compendium of Tools for Watershed Assessment and TMDL Development* (USEPA 1997c). Although updated versions of some models have been released since the compendium was published, it provides a good starting point for researching available models and understanding their capabilities. ☛A more recent online database, provided by EPA’s Council on Regulatory Environmental Modeling, provides links to model reviews and resources (http://cfpub.epa.gov/crem/).

Seven watershed models are presented here for more detailed discussion: AGNPS, STEPL, GWLF, HSPF, SWMM, P8-UCM, and SWAT. The models represent a cross section of simple to more detailed approaches, provide simulation of rural and more urbanized areas, and include a diversity of approaches. These models are used to describe key differentiators and considerations in selecting and applying models.

Other models that have specialized capabilities to support watershed management planning or TMDL development are available. The additional models include

- WAMVIEW for areas where there are high water tables that affect infiltration and runoff
- Models that specialize in detailed sediment detachment and wash-off, such as KINEROS and the Sediment Tool (TMDL Toolbox)
- Specialty models for simulating mercury, such as the TMDL Toolbox Mercury Tool, which provides watershed-scale assessment of mercury loading

The key features of the selected models are presented below. ☛In section 8.4 the model application process for the selected models is described. ☛Appendix A provides resources for more detailed discussion on available models and their applications.

Where to Find the Selected Models

AGNPS
www.ars.usda.gov/Research/docs.htm?docid=5199

STEPL
Temporary URL http://it.tetratech-ffx.com/stepl

GWLF
The original version of the model has been used for 15 years and can be obtained from Dr. Douglas Haith at Cornell University. A Windows interface (Dai et al. 2000) is available at www.vims.edu/bio/vimsida/basinsim.html. Penn State University developed an ArcView interface for GWLF (www.avgwlf.psu.edu) and compiled data for the entire state of Pennsylvania (Evans et al. 2002).

HSPF
HSPF is available through EPA's Center for Exposure Assessment Modeling (www.epa.gov/ceampubl/swater/hspf) and also as part of EPA's BASINS system (www.epa.gov/ost/basins/). Another formulation of HSPF is EPA's Loading Simulation Program in C++ (LSPC), which can be downloaded at www.epa.gov/athens/wwqtsc/html/lspc.html.

P8-UCM
www.wwwalker.net/p8/p8v24.zip

SWAT
www.brc.tamus.edu/swat
SWAT is also included in EPA's BASINS system (www.epa.gov/waterscience/basins/basinsv3.htm).

SWMM
www.epa.gov/ednnrmrl/models/swmm/index.htm

AGNPS

The Agricultural Non-Point Source (AGNPS) model was developed by USDA's Agricultural Research Service for use in evaluating the effect of management decisions on a watershed system. The term "AGNPS" now refers to the system of modeling components, including Annualized AGNPS, rather than the single-event AGNPS, which was discontinued in the mid-1990s. AGNPS has the advantage of providing spatially explicit modeling results, which is not true of most of the other models described here. However, the annualized version has not yet had extensive validation, and the user base is not yet broad. One training opportunity per year is typically offered. ☛The model, documentation, and information about training are available at www.ars.usda.gov/Research/docs.htm?docid=5199.

AnnAGNPS is a continuous-simulation, watershed-scale program developed based on the single-event model AGNPS. AnnAGNPS simulates quantities of surface water, sediment, nutrients, and pesticides leaving the land areas and their subsequent travel through the watershed. Runoff quantities are based on a runoff curve number (CN), while sediment is determined using the Revised Universal Soil Loss Equation (RUSLE; USDA 1996). Special components are included to handle concentrated sources of nutrients (feedlots and point sources), concentrated sediment sources (gullies), and added water (irrigation). Output is expressed on an event basis for selected stream reaches and as source accounting (contribution to outlet) from land or reach components over the simulation period. The model can be used to evaluate the effect of management practices such as agricultural practices, ponds, grassed waterways, irrigation, tile drainage, vegetative filter strips, and riparian buffers. All runoff and associated sediment, nutrient, and pesticide loads for a single day are routed to the watershed outlet before the next day's simulation. There is no tracking of nutrients and pesticides attached to sediment deposited in stream reaches from one day to the next. Point sources are limited to constant loading rates (water and nutrients) for the entire simulation period, and spatially variable rainfall is not allowed. ☛The model is available at www.ars.usda.gov/Research/docs.htm?docid=5199.

Physically Based Models

A physically based model includes a more detailed representation of processes based on physical features. Applying physically based models requires extensive data to set up and test the model and substantial modeling experience. HSPF and SWAT both include physically based processes, although many simplifications are used.

AGNPS was developed for agricultural or mixed-land-use watersheds. It predicts nitrogen, phosphorus, and organic carbon. It is appropriate for use on watersheds of up to 500 square kilometers. It provides information on the impact on various locations in the watershed, rather than simply various land uses.

STEPL

STEPL is a simplified spreadsheet tool for estimating load reductions that result from implementing management practices. It is designed as a customized Excel spreadsheet model that is easy to use. Users can modify the formulas and default parameter values without any specialized programming skills. STEPL includes a management practice calculator that computes the combined effectiveness of multiple management practices implemented in serial or parallel configurations (or both) in a watershed. Management measures that affect hydrology or sediment can be estimated with empirical factors, such as the Soil Conservation Service (SCS; now the Natural Resources Conservation Service [NRCS]) CN for estimating runoff and USLE *C* and *P* factors representing vegetative cover and conservation practices, respectively. (☛More detail on selecting CNs and USLE parameters is included in section 8.4.3.) Pollutant load reductions attributable to the management practices are estimated with reduction factors (or management practice effectiveness) applied to the pre-management practice loads from the various land uses. ☛The user's guide, model, default database, and other supporting information are available on the STEPL Web site (temporary URL http://it.tetratech-ffx.com/stepl). Application of the STEPL tool requires users to have a basic knowledge of hydrology, erosion, and pollutant loading processes. Familiarity with the use and limitations of environmental data is also helpful. Computer skills in Microsoft Excel and the use of Excel formulas are needed.

GWLF

The Generalized Watershed Loading Function (GWLF) model simulates runoff and sediment delivery using the SCS curve number equation (CNE) and the USLE, combined with average nutrient concentration based on land use. GWLF is a good choice for watershed planning where nutrients and sediment are primary concerns. Because of the lack of detail in predictions and stream routing (transport of flow and loads through the stream system), the outputs are given only monthly, although they are calculated daily.

The model is simple enough that most people should be able to learn it without attending training sessions. The original version of the model has been used for 15 years. Data requirements are low: information on land use, land cover, soil, and the parameters that govern runoff, erosion, and nutrient load generation is all that is required. ☛Pennsylvania State University developed an ArcView interface for GWLF (www.avgwlf.psu.edu) and compiled data for the entire state of Pennsylvania (Evans et al. 2002). A Windows interface (Dai et al. 2000) is also available at www.vims.edu/bio/vimsida/basinsim.html. Calibration requirements for GWLF are very low. GWLF is a good choice for watershed planning in many situations. The interfaces and documentation are excellent, and the model is quite easy to use. The management practice tool (PRedICT) is a good, simple way to estimate the impact of management practices. However, GWLF is limited to nutrient and sediment load prediction and it does not include instream processes such as flow and transport of loads.

HSPF

The Hydrologic Simulation Program–Fortran (HSPF) is a comprehensive package for simulating watershed hydrology and water quality for a wide range of conventional and toxic organic pollutants. HSPF simulates watershed hydrology, land and soil contaminant runoff, and sediment-chemical interactions. The model can generate time series results of any of the simulated processes. Overland sediment can be divided into three types of sediment (sand, silt, and clay) for instream fate and transport. Pollutants interact with suspended and bed sediment through soil-water partitioning. HSPF is one the few watershed models capable of simulating land processes and receiving water processes simultaneously. It is also capable of simulating both peak flow and low flows and simulates at a variety of timesteps, from subhourly to one minute, hourly, or daily. The model can be set up as simple or complex, depending on application, requirements, and data availability. For land simulation, processes are lumped for each land use type at the subwatershed level;

therefore, the model does not consider the spatial location of one land parcel relative to another in the watershed. For instream simulation, the model is limited to well-mixed rivers and reservoirs and one-directional flow. HSPF requires extensive calibration and generally requires a high level of expertise for application.

The most recent release is HSPF Version 12, which is distributed as part of the EPA BASINS system. Another formulation of HSPF is EPA's Loading Simulation Program in C++ (LSPC), a watershed modeling system that includes algorithms for simulating hydrology, sediment, and general water quality on land, as well as a simplified stream transport model (www.epa.gov/athens/wwqtsc/html/lspc.html). A key advantage of LSPC is that it has no inherent limitations in terms of modeling size or model operations and has been applied to large, complex watersheds. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel. Data management tools support the evaluation of loading and management within multiple watersheds simultaneously.

P8-UCM

The P8-UCM program predicts the generation and transport of stormwater runoff pollutants in small urban catchments. It consists mainly of methods derived from other tested urban runoff models (SWMM, HSPF, D3RM, TR-20). Model components include stormwater runoff assessment, surface water quality analysis, and routing through structural controls. The model applications include development and comparison of stormwater management plans, watershed-scale land use planning, site planning and evaluation for compliance, effectiveness of sedimentation ponds and constructed wetlands, and selection and sizing of management practices.

Simulations are driven by continuous hourly rainfall and daily air temperature time series data. The model simulates pollutant transport and removal in a variety of urban stormwater management practices, including swales, buffer strips, detention ponds (dry, wet, and extended), flow splitters, and infiltration basins (offline and online); pipes; and aquifers. The model assumes that a watershed is divided into a lumped pervious area and a lumped impervious area and does not evaluate the spatial distribution of pervious and impervious land uses. The model also assumes that pollutants entering the waterbodies are sediment-adsorbed. P8-UCM is a simple model that requires moderate effort to set up, calibrate, and validate. Limitations of the model include limited capability in flow and pollutant routing and limited capability in ground water processes and ground water and surface water interaction.

SWAT

The Soil and Water Assessment Tool (SWAT) was developed by the USDA's Agricultural Research Service (ARS) and is one of the models in the EPA BASINS modeling system. SWAT is included in EPA's BASINS v3.1—

www.epa.gov/waterscience/basins/basinsv3.htm. SWAT is strongest in agricultural areas; the urban component was added more recently. Pollutants modeled are pesticides, nutrients, sediment based on agricultural inputs, and management practices. The bacteria component has been developed but is still being tested. SWAT has been validated in many watersheds. It is more comprehensive than GWLF and can better estimate the water quality impacts of some management changes; however, the added accuracy gained by running SWAT will be worth the extra effort only in watersheds where high-resolution agricultural management analyses are warranted and where information on agricultural land use practices can be obtained.

SWMM

SWMM is a dynamic rainfall-runoff simulation model developed by EPA. It is applied primarily to urban areas and for single-event or long-term (continuous) simulation using various timesteps (Huber and Dickinson 1988). It was developed for the analysis of surface runoff and flow routing through complex urban sewer systems. SWMM was first developed in 1971 and has undergone several major upgrades. The current edition, Version 5, is a complete rewrite of the previous release and was produced by EPA's National Risk Management Research Laboratory. ☛For more information on SWMM and to download the current version, go to www.epa.gov/ednnrmrl/models/swmm/index.htm.

The model performs best in urbanized areas with impervious drainage, although it has been widely used elsewhere. SWMM has been applied to urban hydrologic quantity and quality problems in a number of U.S. cities, as well as extensively in Canada, Europe, and Australia (Donigian and Huber 1991; Huber 1992). In addition to its use in developing comprehensive watershed-scale planning, typical uses of SWMM include predicting CSOs, assessing the effectiveness of management practices, providing input to short-time-increment dynamic receiving water quality models, and interpreting receiving water quality monitoring data (Donigian and Huber 1991).

In SWMM, flow routing is performed for surface and sub-surface conveyance and ground water systems, including the options of non-linear reservoir channel routing and fully dynamic hydraulic flow routing. In the fully dynamic hydraulic flow routing option, SWMM simulates backwater, surcharging, pressure flow, and looped connections. SWMM has a variety of options for water quality simulation, including traditional buildup and wash-off formulation as well as rating curves and regression techniques. USLE is included to simulate soil erosion. SWMM incorporates first-order decay and particle settling mechanisms in pollutant transport simulations and includes an option of simple scour-deposition routine. The latest version of SWMM simulates overland flow routing between pervious and impervious areas within a subcatchment. Storage, treatment, and other management practices can also be simulated. The model typically requires calibration of its parameters for water quantity and quality simulations. The model also assumes all pollutants entering the waterbodies are sediment adsorbed.

8.3.5 Capabilities of the Selected Models

Major factors in selecting a watershed model include

- Water quality indicators simulated
- Simulation of land and water features (e.g., land use and waterbody types)
- Application considerations (e.g., training required)

The following sections discuss the capabilities and characteristics of the selected models for each of these considerations.

Water Quality Targets or Endpoints for the Selected Models

The selection of the appropriate model for your watershed and your goals depends on the types of processes you need to simulate. The initial criteria for determining which model is right for your watershed analysis include the water quality targets or goals. Water quality targets are based on specific parameters (e.g., phosphorus, sediment) and typically have an associated magnitude, duration, and frequency. For example, a target might be established for a monthly sediment load of 20 tons, or bacteria targets might be set as a daily maximum of 400 counts/100 mL. To better summarize the selected watershed models' applicability to typical water quality targets and to aid in identifying appropriate models for your watershed, table 8-5 summarizes the models' ability to simulate typical target pollutants and expressions (e.g., load vs. concentration). The table scores the models depending on the timestep of the simulation for the target—annual, daily, or hourly.

Simulation of Land and Water Features

After you've initially identified models based on the necessary parameters, it's important to identify the major land and water features or processes that you want to simulate. For example, what types of land uses are in your watershed? Is ground water an important influence on instream water quality? Are there certain types of management measures you want to evaluate in your watershed? The available models simulate different land and water features, and they do so at different levels of detail. Table 8-6 provides a summary of the selected key models' capabilities for simulating a variety of land and water features. The table identifies the following categories:

- **General Land and Water Features Supported:** Rates models according to their ability to simulate general land uses and waterbody types.

- **Special Land Features Supported:** Rates models on the basis of their ability to simulate special land processes such as wetlands, hydrologic modification, urban management practices, and rural management practices.

Table 8-5. Water Quality Endpoints Supported by the Selected Watershed Models

Parameter/Endpoint	AGNPS	STEPL	GWLF[a]	HSPF	P8-UCM	SWAT	SWMM
Total phosphorus (TP) load	◗	❍	◗	●	●	◗	●
TP concentration	◗	–	◗	●	●	◗	●
Total nitrogen (TN) load	◗	❍	◗	●	●	◗	●
TN concentration	◗	–	◗	●	●	◗	●
Nitrate concentration	–	–	–	●	–	◗	●
Ammonia concentration	–	–	–	●	–	◗	●
TN:TP mass ratio	–	–	◗	●	–	◗	●
Dissolved oxygen	◗	–	–	●	–	◗	●
Chlorophyll a	–	–	–	●	–	◗	–
Algal density (mg/m^2)	–	–	–	–	–	–	–
Net total suspended solids load	–	❍	–	●	●	–	●
Total suspended solids concentration	◗	–	–	●	●	◗	●
Sediment concentration	◗	–	◗	●	●	–	●
Sediment load	◗	❍	◗	●	–	◗	●
Metals concentrations	–	–	–	●	–	◗	●
Pesticide concentrations	◗	–	–	●	–	◗	–
Herbicide concentrations	◗	–	–	●	–	◗	–
Toxic substances concentrations	–	–	–	●	–	–	–
Pathogen count (*E. coli*, fecal coliform)	–	–	–	●	–	◗	●
Temperature	–	–	–	●	–	◗	–

Key:
– Not supported
❍ Annual
◗ Daily
● Hourly
[a]GWLF calculations are performed on a daily basis, but the results are presented on a monthly basis.

- **Special Water Features Supported:** Rates models on the basis of their ability to simulate special processes occurring in receiving waterbodies such as air deposition, streambank erosion, algae, and fish. Because the selected models are primarily watershed models, many of the detailed water features are not supported. If these processes are important in your watershed, it might be necessary to investigate receiving water models or other outside analyses to use in combination with your watershed model.

Application Considerations

Another issue to consider when selecting your model is what it takes to apply the model—considerations such as how long it will take to setup and apply the model, how much training you'll need, and how much the model will cost. Table 8-7 rates the selected models based on the practical considerations affecting their application. Models with filled circles are generally easier to use and require less data and time for application.

Table 8-6. Land and Water Features Supported by the Selected Watershed Models

Land and Water Feature	AGNPS	STEPL	GWLF	HSPF	P8-UCM	SWAT	SWMM
General Land and Water Features							
Urban	–	❍	◗	◗	◗	◗	●
Rural	●	❍	◗	●	❍	●	◗
Agriculture	●	❍	◗	●	❍	●	❍
Forest	–	❍	◗	●	❍	●	❍
River	–	–	❍	●	❍	❍	❍
Lake	–	–	–	◗	–	❍	❍
Reservoir/impoundment	–	–	–	◗	◗	❍	◗
Estuary (tidal)	–	–	–	–	–	–	–
Coastal (tidal/shoreline)	–	–	–	–	–	–	–
Detailed Land Features							
Air deposition	–	–	–	❍	–	–	–
Wetland	–	–	–	◗	❍	❍	❍
Land-to-land simulation	❍	–	–	❍	–	–	–
Hydrologic modification	–	–	–	◗	–	–	◗
Management practice siting/placement and optimization	●	–	–	❍	◗	–	◗
Urban Land Management							
Street sweeping	–	–	❍	–	◗	❍	◗
Nutrient control practices (fertilizer, pet waste management)	◗	–	–	❍	❍	❍	❍
Stormwater structures (manhole, splitter)	–	–	–	–	❍	–	◗
Detention/retention ponds	◗	–	–	❍	◗	❍	◗
Constructed wetland processes	–	–	–	–	❍	❍	❍
Vegetative practices	◗	–	❍	❍	❍	❍	❍
Infiltration practices	–	–	–	❍	❍	–	–
Rural Land Management							
Nutrient control practices (fertilizer, manure management)	●	❍	❍	●	–	●	❍
Agricultural conservation practices (contouring, terracing, row cropping)	●	❍	❍	●	–	●	❍
Irrigation practices/tile drains	–	–	–	–	–	●	–
Ponds	◗	–	–	◗	◗	◗	◗
Vegetative practices	◗	❍	❍	❍	–	◗	–

Key:
– Not supported
❍ Low: Simplified representation of features, significant limitations
◗ Medium: Moderate level of analysis, some limitations
● High: Detailed simulation of processes associated with land or water feature

Table 8-7. Application Considerations of the Selected Watershed Models

Application Considerations	AGNPS	STEPL	GWLF	HSPF	P8-UCM	SWAT	SWMM
Experience required	◗	●	●	–	●	❍	–
Time needed for application	◗	●	●	–	●	◗	❍
Data needs	◗	●	●	❍	●	◗	❍
Support available	◗	❍	❍	●	❍	◗	◗
Software tools	◗	●	●	●	❍	●	❍
Cost to purchase	●	●	●	●	●	●	●

Key:

Experience:
- – Substantial training or modeling expertise required (generally requires professional experience with advanced watershed and/or hydrodynamic and water quality models)
- ❍ Moderate training required (assuming some experience with basic watershed and/or water quality models)
- ◗ Limited training required (assuming some familiarity with basic environmental models)
- ● Little or no training required

Time Needed for Application:
- – > 6 months
- ❍ > 3 months
- ◗ > 1 month
- ● < 1 month

Data Needs:
- ❍ High
- ◗ Medium
- ● Low

Support Available:
- – None
- ❍ Low
- ◗ Medium
- ● High

Software Tools:
- – None
- ❍ Low
- ◗ Medium
- ● High

Cost to Purchase:
- – Significant cost (> $500)
- ❍ Nominal cost (< $500)
- ◗ Limited distribution
- ● Public domain

8.4 Model Application Process for the Selected Models

Previous sections discussed the basic features of models, how to select appropriate models for your project, and general steps in applying models. This section discusses the decisions made during model application. Although the models have different features and capabilities, some basic decisions regarding data and data processing are required for every model application. The major data needs for the selected models reviewed here are summarized in table 8-8. These are the decisions that result in tailoring the model to your specific site. Each major decision point is discussed, along with some suggestions for how to decide the appropriate level of detail.

For loading analysis you need to think carefully about the area being modeled. A watershed is usually composed of areas with diverse land uses and activities. Some watersheds have regional differences, such as a densely populatd areas surrounded by countryside. When applying a model to a watershed, the diversity within the watershed is simplified into major categories so that the loads can be estimated. If the analysis is too detailed, the modeling becomes very difficult to apply and test. If the analysis is too simplified, some important information might be lost. Modeling should build on the detailed understanding of the watershed developed during planning and data analysis.

Table 8-8. Typical Data Needs for Example Models

Model	Number of Watersheds	Land Use and Soil Parameters	Stream Channel Characteristics	Nutrient Applications	Management Practices
AGNPS	> 1	CN/USLE	N/A	Application rate	Location and type associated with land use
STEPL	1	CN/USLE	N/A	N/A	General type
GWLF	1	CN/USLE	N/A	Manure/nutrient applications, date	General/agricultural
HSPF	> 1	HSPF-specific	Flow/discharge relationships, length	Application rate	Location and type
P8-UCM	1	CN/USLE	N/A	N/A	General type
SWAT	> 1	CN/USLE	Dimensions of stream channel	Application rate	Location and type associated with land use
SWMM	> 1	Green-Ampt/USLE	Dimensions of stream channel, conduits, and pipes	Buildup and wash-off rates	Location and type associated with land use

Note: CN = curve number; USLE = Universal Soil Loss Equation.

8.4.1 Watershed Delineation

Although you've already delineated your watershed (section 5.4.1), you'll likely further divide the watershed into small subwatersheds for modeling and evaluation. Dividing the watershed into subwatersheds is usually the very first step in watershed modeling. A watershed of 10 square miles might be subdivided into 20 subwatersheds about 0.5 square mile each. How do you decide how small to go? That will depend on the watershed characterisitics, the type of model you're using, and the management actions that might be considered. Some watershed characteristics to consider when subdividing the watershed include

- Land use distribution and diversity
- Location of critical areas
- Stream gauging stations and water quality monitoring locations (subwatersheds should match key monitoring locations for testing)
- Location of physical features such as lakes, dams, and point sources discharges
- Changes in topography
- Soil distribution
- Areas where management might change

Table 8-9 provides examples of the number of subwatersheds and average size of subwatersheds for some very large watershed modeling applications using HSPF or LSPC. Why do they vary significantly? The watershed with the most uniform land uses and a large area was evaluated using large subwatersheds (e.g., Tongue River watershed in Montana). The watershed with the smallest subwatersheds is in an area that ranges from highly urbanized to rural and has a dense network of monitoring data available for testing. In this application the local conditions are represented by using smaller watersheds. Each application is unique, and watersheds are defined accordingly.

Table 8-9. Examples of Number and Size of Subwatersheds in Modeling Applications

Watershed	Location	Watershed Size (mi^2)	Number of Subwatersheds	Average Subwatershed Size (mi^2)
Mobile River Basin	AL/GA/MS/TN	43,605	152	286.88
French Gulch Creek	AZ	16	26	0.62
Boulder Creek	AZ	138	9	15.33
Clear Lake Watershed	CA	441	49	9.00
San Gabriel River	CA	689	139	4.96
San Jacinto River	CA	770	32	24.06
Los Angeles River	CA	834	35	23.83
Sacramento River	CA	9,147	249	36.73
Lake Tahoe Watershed	CA/NV	314	184	1.71
Christina River	DE/MD/PA	564	70	8.06
Tug Fork River	KY/VA/WV	1,500	455	3.30
Upper Patuxent River	MD	130	50	2.60
Lower Tongue River	MT	3,609	30	120.30
Lake Helena Watershed	MT	616	49	12.57
Wissahickon Creek	PA	64	5	12.80
Tyger River	SC	750	75	10.00
Salt River	USVI	5	13	0.38
Tygart Valley River	WV	1,362	1,007	1.35
West Fork River	WV	880	645	1.36

The number and size of subwatersheds can affect the model selection process. Some watershed models have limitations on the number of subwatersheds or the size of the area the model can simulate. HSPF, SWMM, and SWAT are typically used for multiple subwatersheds, allowing for the evaluation of geographic distributions of loads. Models such as GWLF and STEPL do not inherently handle multiple watersheds and therefore are applied to one watershed at a time.

How are subwatersheds delineated? Most applications today use a geographic information system (GIS) to delineate watersheds based on Digital Elevation Models (DEMs) and topographic maps. Some software packages provide autodelineation tools or other aids to help define hydrologic boundaries. Predefined watershed boundaries such as 14-digit hydrologic units can be used. ☛See section 5.4.1 for more details on delineating watersheds.

8.4.2 Land Use Assignment

Land use information is typically provided as a GIS coverage or map with many individual codes that describe detailed land use types. For modeling purposes, these individual codes should be grouped into a more managable set of dominant land use types. How much combining is done depends on the watershed characteristics. Factors to consider in deciding on land use grouping include the following:

- Dominant land use types
- Land uses subject to change or conversion
- Land use types where management changes are expected
- Spatial diversity within the watershed
- Availability of information on individual land use types

When grouping land uses, recognize that the summary of pollutant loading will be presented by land use category. Too many categories of land uses can be difficult to model, test, and report. Too few categories can result in oversimplication and generalization of the watershed conditions. Like so many aspects of watershed analysis, this decision depends on the local conditions and the management concerns being evaluated. When selecting your land use grouping, think about the dominant features of your watershed and how they might change in the future (table 8-10). For example, in a watershed that is dominantly forested, the key land use categories might include various ages of trees (newly established, mature), logging roads, and small residential areas. Changes under consideration might be forest practices/harvesting techniques, road removal, and road management. For this watershed most of the detailed land use categories would relate to forest type and practice. In an urban watershed, forest might be grouped into a single category while numerous densities of urban land uses (e.g., commercial, industrial, high-density urban) are represented in more detail.

Table 8-10. Example Land Use Categories for Watershed Models

Forested Watershed	Urban Watershed
• Mature forest • Scrub/brush • Newly established forest (1–5 years) • Harvested areas (0–1 years) • Dirt roads • Camp areas • Residential	• Low-density residential • Medium-density residential • High-density residential • Commercial • Industrial • Open space

8.4.3 Parameter Selection

> **TIP:** The decisions made regarding data processing for model input are part of the assumptions and potential limitations of the modeling approach. During the application, keep a log of all data-processing steps for later use in documenting and identifying assumptions and limitations.

Once subwatersheds and land uses are defined, the next decisions involve summarizing other spatial information within each subwatershed. For most models, this involves combining information on soils, topography, and land use. For example, models that use the CNE (STEPL, GWLF, SWAT, AGNPS, and P8-UCM) have look-up tables that relate soil, crop type, and management to a CN factor (USDA-NRCS 1986). The CN is used in the model to calculate runoff based on rainfall for specific land areas. For HSPF, an infiltration factor that relates to the soil type associated with each land use is selected.

For example, CN options for cornfields (row crops without conservation treatment) include the following (USDA-NRCS 1986):

Corn	A soil	Good Condition	67
Corn	B soil	Fair Condition	79.5 (Average of the CNs for poor and good conditions)
Corn	B soil	Good Condition	78
Corn	C soil	Poor Condition	88

"Condition" applies to the soil conditions for the area. An area with good-condition soils will likely have a better soil structure, resulting in good infiltration and less runoff. Poor-condition soils are typically more compacted, resulting in less infiltration and more runoff. When setting up the model, you would select the appropriate CN that represents a subwatershed/land use unit.

Similarly, key parameters for sediment predictions in STEPL, GWLF, SWAT, AGNPS, and P8-UCM are based on the USLE and are selected for each subwatershed/land use unit. The USLE includes parameters that relate to slope, length, erosion potential, and cropping practice.

USLE can be written as follows (Wischmeier and Smith 1965, 1978):

$$A = R \times K \times LS \times C \times P$$

Where, *A* represents the potential long-term average annual soil loss in tons per acre per year, *R* is the rainfall and runoff factor by geographic location, *K* is the soil erodibility factor, *LS* is the slope length-gradient factor, *C* is the crop/vegetation and management factor, and *P* is the support practice factor. For example, USLE parameters for a cornfield with 2 percent slope, erodible soils, and convential tillage could be selected as follows:

R = 275 (Clarke County, Georgia)
K = 0.3 (soil textural class = loam)
LS = 0.2008 (2 percent slope and 100 feet of slope length)
C = 0.54 (residue removed, conventional tillage, fall plow)
P = 1 (no supporting practice)

Therefore, average annual soil loss is calculated as

$$A = 275 \times 0.3 \times 0.2008 \times 0.54 \times 1 = 8.9 \text{ ton/acre/year}$$

If no-till is practiced and the soil surface is covered with residues, the *C* factor is 0.11 and the average annual soil loss will be

$$A = 275 \times 0.3 \times 0.2008 \times 0.11 \times 1 = 1.8 \text{ ton/acre/year}$$

The convenience and consistency of the CNE and USLE approaches are one of the reasons that the use of models based on them is prevalent. In many areas the CNE, as applied in the NRCS runoff model TR-20, is also used for predicting flow when designing stormwater ponds and road culverts. Engineers and analysts throughout the country are familiar with these fundamental equations.

Simulation of Management Practices

The selected models reviewed here have various capabilities for the representation of management practices, and they tend to specialize in agricultural and urban practices as listed below:

- Agricultural practices—SWAT, AGNPS, GWLF, STEPL
- Urban practices—P8-UCM, STEPL, SWMM
- Mixed land use—STEPL, HSPF

☛More information on how the selected models simulate management practices and how they can support selection of management strategies is included in section 11.3.

There are, however, some limitations that you should consider when applying models based on these equations. Like any analytical tool, they are generalizations of natural physical processes of runoff and erosion. The CNE is based on a standard storm and uses daily rainfall. That means a very intense storm in which the rainfall falls very quickly is treated in the same way as a slow rainfall that continues throughout the day. This can result in some overpredication or underpredictions of rainfall on a specific day. Similarly, the USLE simplifies the erosion processes of detachment (loosening of surface soils due to rainfall) and wash-off. These processes are also very sensitive to rainfall intensity and localized conditions. HSPF and SWMM are more sensitive to rainfall intensity because they use an hourly or shorter rainfall record. However, this additional detail requires more information and model testing to verify model performance.

8.4.4 Model Testing

How do you know if the model is working appropriately? What kinds of tests can be performed to prove that the model is working? Before embarking on detailed evaluation and statistical testing of a model, you must first check the fundamental performance of the model. Check whether the model is working, evaluate the basic performance, and adjust or verify inputs if necessary. Then test for accuracy. In the early testing process, most modelers look at graphs of observed and simulated data and generalized summaries of flow and loading prediction. Initially, you're looking for ways to improve the model and identify features that might have been missed during setup. In the later part of model testing, you're looking for proof that the model is working well and providing reasonable results.

Testing involves comparing modeling results with observed data. It should focus on the questions the model is designed to answer. If a model is designed to evaluate annual nutrient loads, for example, comparisons are made with flow and nutrient monitoring information. Sometimes, when data are highly limited, model testing is based primarily on comparison with literature values, similar studies in nearby regions, and evaluation using alternative calculation techniques. Figure 8-2 shows idealized model testing points: an upstream small

TIP: Use common sense in testing modeling results. Ask a few key questions: Do the results appear consistent with other studies or literature values? Is the water balance correct? Are the predictions consistent with the types of sources or land uses in the watershed? Are there any missing sources?

watershed (1), a small watershed dominated by a single land use (2), and a downstream point at a USGS flow gauging station (3). In cases where additional data gathering is not possible and historical records are limited, testing might be based on a single downstream location. Testing is best performed at locations where flow gauging and water quality sampling are available, typically at USGS gauging stations. Selection of the subwatershed delineation in the initial model setup should consider the locations of available monitoring and testing points. Then the model output can be compared at the locations where flow and water quality measurements are available.

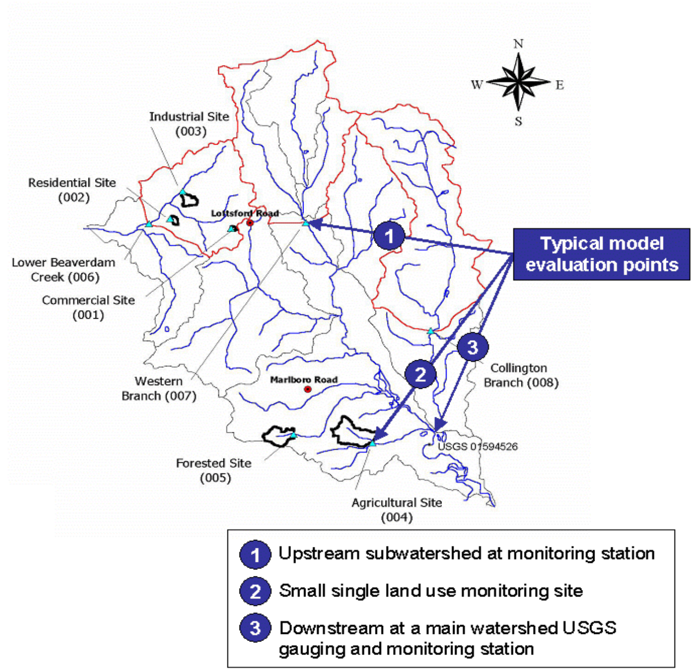


Figure 8-2. Typical model evaluation points.

Some modeling studies require the adjustment or estimation of parameters through a calibration process. For this process the monitoring data are split into two independent periods—calibration and validation. Ideally, these periods are two typical time periods (not extreme conditions) with a range of flow conditions. During the calibration period key parameters are adjusted within reasonable ranges until the best fit with the observed data is determined. The performance of the "calibrated" model is then tested for a separate validation period.

The various model adjustment capabilities for the selected models depend on the techniques used for simulating runoff and pollutant transport (table 8-11). All models that are based on the CNE have limited ability for calibration of flow. Because the CN is selected based on defined look-up tables, only some slight adjustment of a CN for local conditions can be justified. GWLF and SWAT provide for ground water discharges to stream systems, providing an opportunity for calibrating instream flow volume. In this group of models, HSPF provides the most flexibility for adjusting parameters to match local conditons. HPSF includes calibration variables for infiltration, upper and lower zones of soil storage, ground water inputs to streams, and pollutant buildup and wash-off. Although this flexiblity can help tailor the model to local conditions, the number of parameters involved can introduce errors and bias to the analysis as well. Adjustment of parameters must carefully consider the physical processes being represented and the reasonable

Example Calibration Tests

Regression: Model output is plotted against observed data and a regression equation can identify the relationship between modeled and observed values and the goodness of fit. (See figures 8-3 and 8-4 for examples.)

Relative error: Modeled errors are measured by comparing simulated flow values with observed flow values for various time periods (e.g., for the summer) using the following equation:

(Simulated Value – Observed Value)/Observed Value

A small relative error indicates a better goodness of fit for calibration.

Model coefficient of efficiency: This value measures the ratio of the mean square error in model predictions to the variance in the observed data. Values range from minus infinity to 1.0; higher values indicate better agreement.

Student's t-test: This test measures the equality of average modeled concentrations compared to average observed concentrations over various time periods (e.g., the entire calibration period).

Table 8-11. Typical Calibration Options for Selected Example Models

	Flow Calibration	Pollutant Calibration
AGNPS	Limited CN	Nutrient concentrations in water and sediment
STEPL	Limited/CN only	Loading rate
GWLF	Ground water recession	Nutrient concentrations in water (runoff, ground water) and sediment
HSPF	Multiple, infiltration, soil storage, ground water	Pollutant buildup and wash-off, instream transport/decay
P8-UCM	Limited/CN only	Loading rate or more detailed buildup and wash-off of dust and pollutants
SWAT	Ground water	Nutrient concentrations in water and sediment
SWMM	Multiple, infiltration, soil storage, ground water	Pollutant buildup and wash-off, instream transport/decay

ranges for the parameters. SWMM has many of the same infiltration and pollutant wash-off features as HSPF. SWMM has a more simplified approach for erosion simulation using the USLE, and it does not have the ability to simulate detailed land management activies (e.g., manure applications, tillage practices). However, SWMM does include techniques for evaluating structural management practices and pipes typical of urban areas.

There are two major sequences or hierarchies of testing—parameters and time scales. Of all the parameters predicted by the model, flow is always checked first, followed by sediment, and then the various pollutants being simulated (e.g., nutrients, metals). Multiple time scales are also evaluated, including annual, monthly, and daily summaries (figure 8-3). Time periods can also be grouped by seasons to evaluate performance that relates to wet and dry periods reflective of local weather patterns. In addition, for models sensitive to rainfall intensity, such as HSPF, predictions can be evaluated on the basis of storm size. For example, how well does the model predict the smallest 25 percent of all storms?

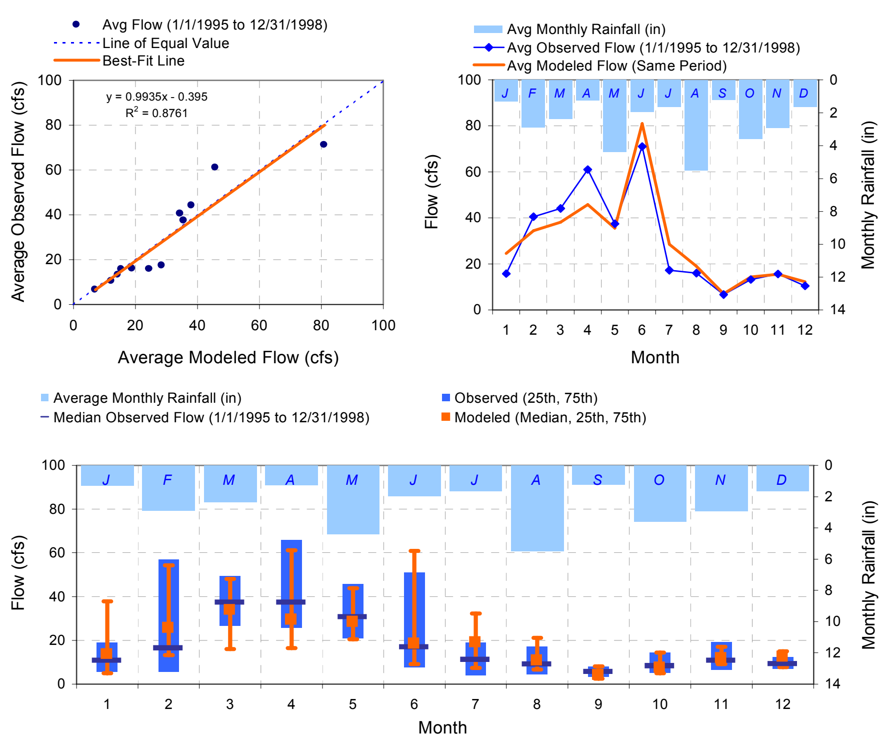


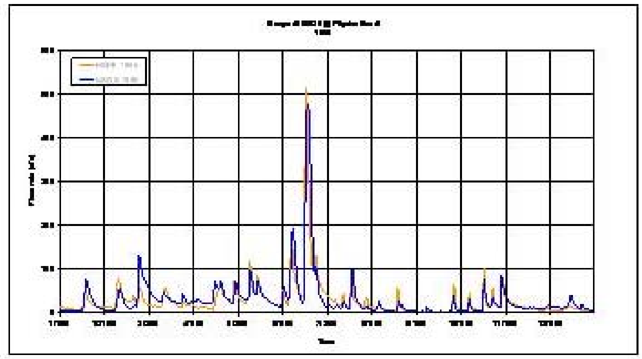
Figure 8-3. Sample calibration tests for hydrologic simulation.

The typical factors used in evaluating model performance include the following:

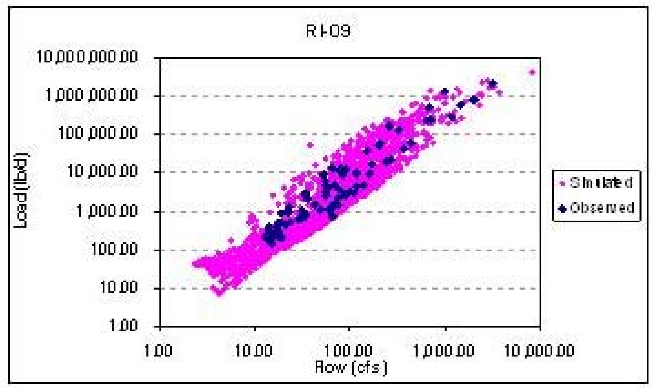
- Water balance (general assessment of precipitation, evaporation, infiltration, and runoff)

- Observed vs. measured flow (daily average, monthly, annual, and flow duration curves) (figure 8-3)
- Observed vs. measured load (annual loads, seasonal variation, source loads)
- Graphs comparing observed vs. modeled flow, load and flow, or frequency plots (figure 8-4)

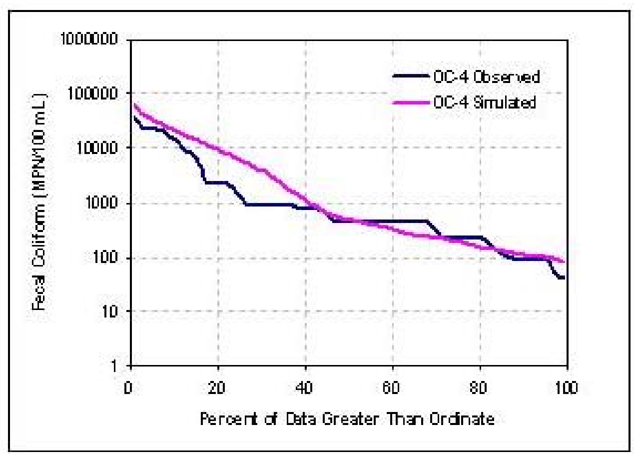
These factors can all be “tested” through graphical evaluation or by applying statisticsl tests to observed data and modeled output (see sibebar for examples). Each test can examine different aspects of performance consistent with the type of model selected and the questions being evaluated. Testing is a process that can be used to diagnose problems with the model setup, improve model simulation, and ultimately confirm that the model is working correctly. You should not rely too heavily on a single test, but use a combination of approaches to get a multifaceted evaluation of model performance. When you start testing the model, watch out for indications that something has been missed during model setup. Sometimes models appear not to work because a source is missing or was incorrectly entered into the model. For example, the model might appear to underpredict flow during low-flow periods. This could be an indication that a point source discharge is missing or that ground water recharge into the stream system is too low. Looking carefully at this low-flow period, when point sources and ground water are the dominant sources, and reviewing local records can help you to diagnose this problem. Always check carefully for missing information before you adjust model parameters to compensate for something you observe. Be careful to keep track of changes and modeling versions so that updates are consistently incorporated into subsequent analyses.



Continuous flows – observed and simulated



Observed load and flow - sediment



Frequency – observed and simulated fecal coliform

Figure 8-4. Sample model testing graphics.

Sometimes local anomolies in geology and hydromodification can significantly affect flow and loading predictions. These local conditions should be considered during the model selection process. Setup and application of models need to specifically account for local geology and hydrologic conditions. Some examples of specialized conditions follow:

- *Unusual hydrology due to local geologic conditions (e.g., karst features).* Some areas have unusual conditions. Streams might disappear or have unusual flow patterns. If these conditions are not well understood or monitored, modeling will be difficult.
- *High water table.* If the water table is very high, rainfall might not infiltrate, or there might be interactions between surface water and ground water.
- *Undiagnosed or undiscovered sources.* If a source is unknown, it won't be in the model. When testing models, you might realize that a source is missing. Additional field reconnaissance or monitoring might be needed to check.

Documenting Model Selection and Application

When using a model as part of a watershed management effort, it's important to document the modeling process. The purpose of documentation is to provide a firm understanding of what the modeling effort represents to the public and planning committee. At a minimum, the model documentation should include the following:

- Model name and version
- Source of model
- Purpose of model application
- Model assumptions (list or summarize); any of the assumptions could limit the usability of the results of the application, and that must be explained
- Data requirements and source of datasets

8.4.5 Estimation of Exising Conditions and Baseline Scenarios

The modeling approaches developed are ultimately designed to support decisionmaking. Essential to decisionmaking is the application of the model to various alternatives. How you use the model to support decisionmaking is as important as the various steps that go into building and testing the model. Typically, models are applied to an existing condition to set a baseline for comparison. Existing conditions can be compared with management alternatives and future conditions. Remember that "existing" is really a reflection of the data used to build the model. If the land use data you're using are 10 years old and were not updated for the study, "existing" will really represent 10 years ago. If residential development includes management practices and you have not included management practices in the model, "existing" conditions might overestimate loads.

TIP: Keep a log of all scenarios considered and the input assumptions used for each.

To estimate existing conditions, you apply the calibrated model to some typical time period and then calculate your loads based on model results. To help understand the watershed loads and their sensitivity to different watershed conditions, it's useful to apply the model to various scenarios that represent some variation of the baseline. Some of the model applications you might want to consider are

- Future land use under various growth or land use conversion scenarios
- Management practice or point source implementation alternatives
- Historical or predevelopment conditions

Ultimately, in designing and selecting management alternatives (discussed in chapters 10 and 11), you can use the model to support selection of the preferred alternative, and estimate the benefits of management implementation.

8.5 Presenting Pollutant Loads

You'll use the information gained from your loading analysis to quantify your watershed pollutant loads. Your loading analysis essentially quantified your loads, but now you have to decide how to present them for use in your watershed plan. Two factors will affect this decision—space and time. You need to decide the spatial resolution for your loads, as well as the time scale for their calculation. You initally made these decisions when you identified your sources (chapter 7), but now you'll refine the spatial and time scales for evaluating and calculating source loads based on your loading analysis.

Table 8-12 summarizes typical scales for calculating and presenting loading results from watershed models. Presentations can use a combination of tables and graphical displays. (Storing information in spreadsheets or databases can facilate comparisons and preparation of graphics.) Developing maps, graphs, bar charts, and piecharts can help to summarize information and facilitate interpretation of results.

Table 8-12. Typical Loading Presentation Categories and Types

Spatial Scale	Land Use	Time Scale
• Watershed • Tributary (multiple-subwatershed) • Region (political or other boundaries) • Subwatershed • Critical areas	• Watershed general land use category (agriculture, urban) • Land use subcategory (cropland, pasture, residential)	• Average annual • Annual • Seasonal • Monthly • Storm • Design storm

8.5.1 Consider Spatial Scales

There are various options for assigning the spatial extent for your load calculations. You can quantify a gross load for the overall watershed or for each land use or even for each land use in each subwatershed. The detail to which you calculate the loads in the watershed will depend primarily on the types and locations of the watershed sources identified during the data analysis. If a spatial analysis of water quality data identified critical areas in the watershed—areas experiencing the most or worst problems and impairments—these areas should be isolated and loadings presented separately. If the watershed is large and has a variety of pollutant sources, it is recommended that you present the loadings by subwatersheds or groupings of subwatersheds, such as larger tributaries (figure 8-5). It is also

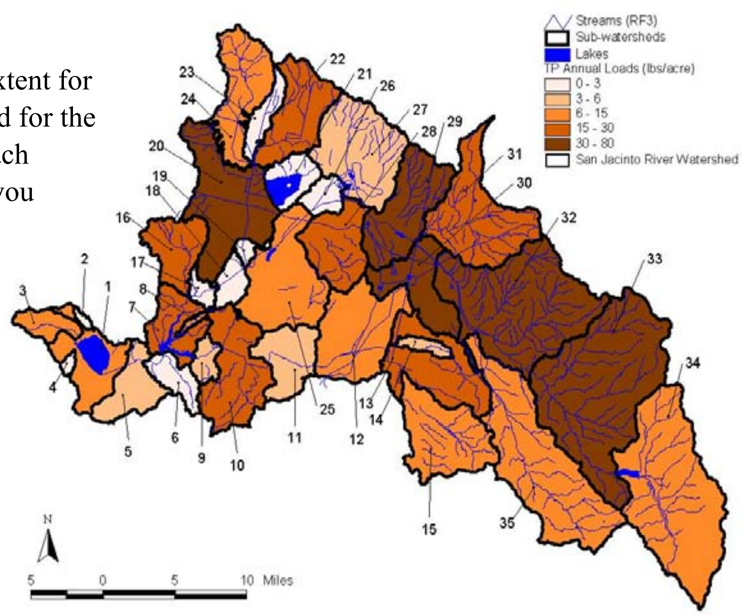


Figure 8-5. Presentation of annual sediment loads (lb/ac) by subwatershed, San Jacinto, California.

useful to calculate loads by land use because many pollutants are associated more with some land uses and less with others. For example, cropland runoff is often a source of nutrients, whereas forested areas are typically less significant sources of nutrients.

8.5.2 Consider Time Scales

The other issue affecting how you present your watershed loads in your watershed plan is the associated time scale. Loads can be calculated for a number of time scales—daily, monthly, seasonal, annual. Like the spatial resolution, the appropriate time scale will depend on the sources and problems in your watershed. The results of the data analyses provide a guide for selecting the appropriate time scale for the loading analysis and ultimate presentation of the loads. For example, analysis of monthly or seasonal water quality conditions identifies the critical times of year in the watershed. If there is considerable variation in water quality throughout the year, given source loading characteristics and weather patterns, it might be necessary to calculate seasonal loads (figure 8-6).

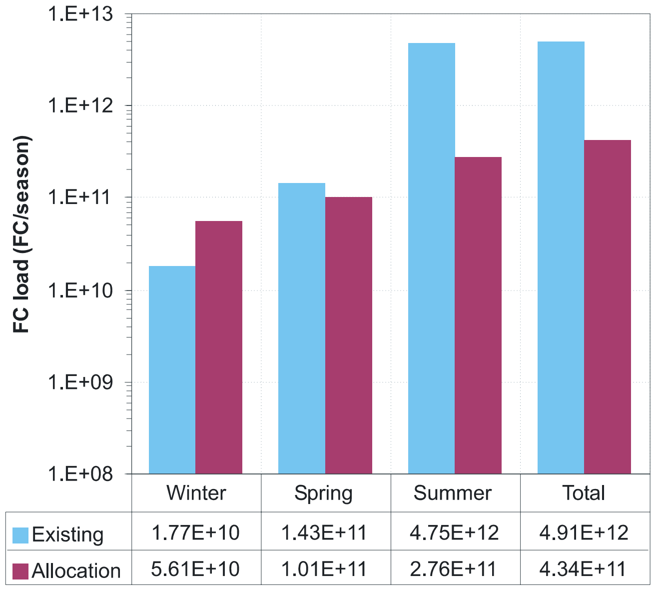


Figure 8-6. Seasonal fecal coliform bacteria loads.

The impairment characteristics and water quality or watershed targets can also affect the loading time scale. Some pollutants, such as bacteria, have more immediate impacts, and associated targets are often based on daily maximums or a geometric mean of instantaneous concentrations. For bacteria, it might be appropriate to use an approach that is capable of calculating daily loads for comparison to water quality targets. Sediment loading, on the other hand, is a chronic problem that has long-term impacts. Occasional high sediment concentrations might not cause problems, but high sediment loading could result in long-term impacts on aquatic habitat. Therefore, it is usually appropriate to evaluate sediment loading on a monthly or annual basis (figure 8-7).

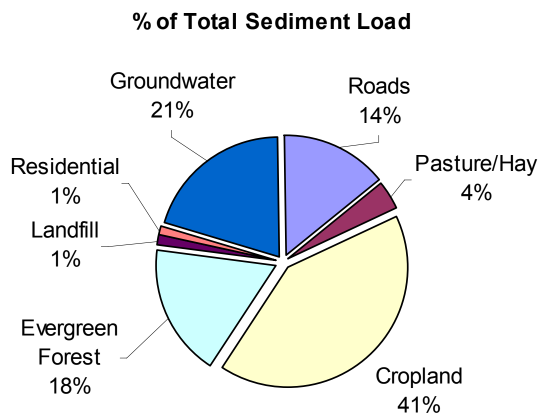


Figure 8-7. Total sediment load and percentages associated with each source.

Keep in mind that how you establish your pollutant loads will affect your ability to evaluate management options. When quantifying the pollutant loads, you're essentially establishing the baseline load that will be reduced to meet your watershed goals. If you establish an overall load for the entire watershed, it will be difficult to assess changes in loads and improvements throughout the watershed. Alternatively, when you establish loads at critical areas (e.g., downstream of a major source, for specific land uses), you can more readily evaluate the direct impact of the surrounding sources and also future management efforts targeted at those sources.

8.5.3 Next Steps in the Development of the Watershed Plan

Now that you've calculated source loads for your watershed, you can move on to the next step of the watershed plan development process—identifying watershed targets and necessary load reductions. The loads you've calculated will provide the basis for identifying the necessary load reductions to meet watershed goals and eventually the implementation of management practices.